https://dx.doi.org/10.22161/ijaers.4.9.4 ISSN: 2349-6495(P) | 2456-1908(O)

Considerations on the Lift Force

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Abstract— *Many authors at criticizing the conventional explanation of aerodynamic lift based on Bernoulli's law commit the same mistake laying within the scope of mechanics and ignoring the effects of viscosity in the generation of forces. Because it is an irreversible process, we affirm that it is not possible to generate lift without increasing entropy. And for an increase of entropy it must be considered the viscosity and vorticity.*
Keywords— viscosity, vorticity, lifting, entropy.

I. INTRODUCTION

The Lift force (L) is an extraordinary force, especially when trying to understand how it is possible for an aircraft, such as an Airbus, to take off and fly so smoothly. The lift force is the component of the aerodynamic force acting in the direction perpendicular to the air flow. The other component of aerodynamic force is the drag that acts against the body's motion. Both depend on pressure distributions and shear stresses (FOX and McDONALD(4), 2001; ANDERSON(2), 2001).

The Lift force L can be represented by:

$$L = CL\, \rho\, v^2\, S / 2,$$

where CL is the lift coefficient, determined for each wing profile and which varies according to the angle of attack, ρ is the specific mass of air; S is the projected area over the plane perpendicular to the wind direction and v is the wind speed relative to the aerodynamic profile (relative wind).

II. CIRCULATION, VORTICITY AND TURBULENCE

ALLEN(1) (1982) comments that when an ideal flow is produced around a cylinder such that all flow lines are concentric circles, the observed motion is defined as circulation. According to other authors, circulation is a mathematical concept applied to the flow of fluids: the scalar product line integral of velocity v with the line element ***dl*** (WELTNER(6) et al). If this integration is carried out along a closed path and is not null, its value is the circulation, Γ, this is é:

$$\Gamma = \oint \mathbf{v}.d\mathbf{l}\ .$$

Considering this constant magnitude throughout the flow region of an ideal flow, the velocity is inversely proportional to the radius, that is

$$v = \Gamma/2\pi r$$

If the flow of circulation around the cylinder is superimposed by a linear flow on the cylinder, a holding force is produced perpendicular to the direction of flow. Vortex is a portion of the fluid in rotational motion and vorticity, ω, is the measure of the rotational motion of a small element of fluid whose numerical value is equal to twice the value of the mean angular velocity, this is

$$\omega = 2\langle\Omega\rangle$$

In vector terms, vorticity is defined as the rotational velocity vector, such that

$$\boldsymbol{\omega} = \nabla \mathrm{x} \mathbf{v}.$$

Vorticity also appears in turbulence which is a flow of a fluid characterized by chaotic and stochastic property changes. The turbulence translates into the irregular fluctuation of velocity that overlaps with that of the flow (ALLEN(1), 1982) and will not be discussed in this work.

There are authors who present circulation as the cause of the velocity distribution around the wing, but others consider it only a mathematical description of velocity distribution, but not an explanation of the phenomenon.

KUTTA E JOUKOWSKI (cited by WELTNER(5) et al, 2001) showed separately that the circulation Γ and the support L are related.

The formula of the support they found, called the Kutta-Joukowski theorem, is thus written:

$$L = \rho v \Gamma\ ,$$

where v is the relative wind speed or the undisturbed flow, ρ is the specific mass of the air and L is the lift per unit length (L / l).

Note that without circulation there is no support and that to have circulation there must be viscosity! The idea is more or less equivalent to walking: to go forward you have to push the floor back.

According WU(14) the viscous origin of circulation theory has been recognized for a long time, mainly because of the research of Von Karman, Millikan, Howardh, Sears etc, who have recognized some aspects of the viscous phenomena that produce circulation.

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III. THE CAUSE OF LIFT FORCE

ANDERSON[2] (2001) in Fundamentals Aerodynamics writes on p. 294: "We emphasize that the resulting aerodynamic force in a body immersed in a flow is due to the net effect of the integration of pressure distributions and shear stresses on the surface of the body. Furthermore, we note that such support on an airfoil surface is primarily due to the distribution of surface pressure and that shearing has virtually no effect on the support. It is easy to see why. Consider, for example, a standard airfoil. Remember that the pressure acts normal to the surface, and for these support surfaces the direction of this normal pressure is essentially vertically, that is, in the direction of the lift. In contrast, the shear acts tangentially to the surface, and for these support surfaces the direction of this tangential shear stress is mainly in the horizontal direction, ie the direction of drag. Thus, pressure is the dominant element for lift generation and shear stress has an insignificant effect on lift ".

However, if we lived in a perfectly invested world the surface of an airfoil would not produce lift. Certainly, the presence of viscosity is the fundamental reason why we have the support. Viscosity produces the circulation and this generates the support according to the Kutta-Joukowski theorem. This seems strange, even contradictory, taking into account what the author said about the insignificance of shear in the generation of support. What happens then?

The answer is that in real life, this is the way that nature has found to make the flow smoother on the trailing edge, that is, it is the mechanism nature uses to not give infinite speed at the trailing edge. Nature imposes Kutta's condition through viscosity (ANDERSON [2]).

Thus, we are brought to the most ironic situation that may seem, ie, the calculation of the pressure distribution on the surface generates support, although the sustenance cannot exist in a world invested by the conditions of Kutta. Following the conditions of Kutta, we can say that without viscosity we cannot have sustentation, for having no circulation. Another important observation to be made is that without power, no lift can be generated.

IV. LUDWIG PRANDTL'S LIMIT LAYER THEORY

The physical effects, which involved the uncovered support force, from the beginning of the last century were of fundamental importance in the development of flight theory, especially from the boundary layer theory formulated by Ludwig Prandtl in a seminal lecture Delivered at the Heidelberg mathematical congress in 1904 and titled, "On the Motion of a Fluid with Too Little Attrition." Prandtl notes that for a given flow, the classical fluid theory could be applied in a very narrow region, called the boundary layer, adjacent to the wall where the viscous effects should be considered (outside the boundary layer the potential flow applies). Prandtl made some simplifications of the Navier-Stokes equations, and analyzed the part of the flow at which the viscosity is significant. By better understanding the technical details of the boundary layer one can then deal with such difficult problems as the separation of flows and the physical mechanisms behind the Kutta condition.

We must not forget that the boundary layer is the region of the flow where the fluid interacts mechanically and thermally with the solid. Therefore, the recognition of the existence of the boundary layer constituted in the first pass for the understanding of the mechanism of friction in the wall and heat exchange, hence the entropy variations (FREIRE[6]).

It is also observed that for high Reynolds numbers the shear layer must be very thin, that is, when the flows happen to large Reynolds numbers, the viscous effects are only of great importance in the region of the boundary layer.

The literature on boundary layer and support is vast and numerous authors discuss the theme, for example, PRANDTL[10], SCHLICHTING and GERSTEN[13], MUNSON[8]et al). We can deduce that a body immersed in the flowing stream of a fluid experiences forces and moments resulting from this interaction (MUNSON [8] et al).

The characteristic of the flow around a body depends on several parameters such as body shape, velocity, orientation and properties of the fluid flowing on the body. The most important parameters to describe the air flow over a body are: the Reynolds number and the Mach number.

In the region of the boundary layer, a shear stress τ acts. For a Newtonian fluid, τ is directly proportional to the velocity gradient, du/dy, and the coefficient of proportionality μ represents the dynamic viscosity of the fluid, which depends on the temperature.

The viscosity of the air causes the particles near the aerodynamic profile to adhere so that the velocity of these particles tends to zero. Moving away from the adhesion region, the particles are braked due to the friction between them, but with much less intensity.

The further away from the surface of the airfoil, the greater the velocity of the air particles, so that at a certain distance the stream maintains the same relative wind speed.

According to OLIVEIRA[9], the vortices are characterized by high-velocity circular flow with a high kinetic energy load, so they can transfer some of this energy to the "boundary layer", avoiding their early stagnation and separation.

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This transfer of energy to the "boundary layer" allows an increase in the angle of attack and, consequently, of the lift, without the airplane entering into "loss", but at the expense of an increased drag force.

When boundary layer separation occurs, the flow is very turbulent and there is even reversal of flow direction, causing a drastic decrease in lift force, increased drag, and loss of control and stability.

TOWNSEND (cited by LAMESA e SOARES [7]) Suggested that the vorticity of the mean flow and the energy content of turbulent motions are due to coherent anisotropic swirls, also called attached eddies.

These are involved by a fluid containing swirls of scales much smaller, statistically isotropic.

Numerous field and laboratory experiments conducted over the last three decades suggest that organized and coherent eddies are responsible for most heat transfer and momentum in boundary layer (C_L) flows.

It is also found that, superimposed on these coherent movements, there are less organized whirlwinds on a small scale.

V. FINAL CONSIDERATIONS

For ROSA[9], the viscosity is responsible for the generation of vorticity in the region of the boundary layer and this is due to the non-slip of the fluid in the contours of the body.

Vorticity is concentrated in the boundary layer being subject to both viscosity diffusion and convection, by the action of the inertia forces of the flow according to the vorticity transport equation:

$$(D\boldsymbol{\omega}/Dt) = (\boldsymbol{\omega}.\ \nabla)\ V + \upsilon\ \nabla^2\ \boldsymbol{\omega},$$

where $\boldsymbol{\omega}$ is the vorticity, υ is the kinematic viscosity, V is the velocity of the fluid, the term $(\boldsymbol{\omega}.\nabla)V$ represents the convection and the term $\upsilon\nabla^2\boldsymbol{\omega}$ represents the diffusion.

The thickness of the boundary layer can be used as a measure of diffusion of the vorticity in the flow. Large boundary layer thicknesses indicate that vorticity has had time to diffuse, while small thicknesses indicate that convection of vorticity is more important, not allowing time for diffusion.

The entropy variation can be due to conduction heat flux, viscous dissipation, other heat sources and other irreversibilities. For the support problem, we are interested in verifying the variation of the entropy due to the viscous dissipation.

A mechanical friction process to convert the mechanical energy of motion into thermal energy tends to a heating, that is, tends to increase the temperature.

We can say that energy dissipated by friction because it is an irreversible process leads to an increase in entropy. On the other hand, the increase in entropy is also related to circulation, yy means of the equation:

$$(d\Gamma/dt) = -\oint(dp/\rho),$$

and the relationship

$$T\ dS = cp\ dT - (dp/\rho g).$$

offering as a result, (DOMMASCH [3]):

$$(d\Gamma/dt) = g\oint TdS,$$

where Γ é is the circulation, T is the temperature, S is the entropy, cp is the specific heat at constant pressure, p is the pressure, g is the acceleration of gravity and ϱ is the specific mass.

Hence, if there is no variation in the entropy, there is no variation in the circulation. Therefore, the rotational motion is a result of a change in entropy unless the flow is isothermal.

The particular case of this variation is null, that is, $(d\Gamma/dt)=0$ constitutes Kelvin's theorem, treated in the book Dynamics of Fluids of HUGLES[12].

According to the condition of Kutta and with the Kutta-Joukowski theorem to have sustentation it is necessary that there be viscosity and circulation.

Therefore, to sustain in an airfoil it is necessary that an increase in entropy occurs, which can be seen by the previous result of DOMMASCH[3].

Thus, if there is no variation in entropy, there is no change in circulation. In an invincible, purely mechanical world, there would be no point in speaking of irreversibility (a thermodynamic result), for there would be no friction, no heat, and therefore no drag and no Lift.

Finally one could inquire that being an irreversible process the temperature should increase on the surface of the body.

It should not be forgotten, however, that the body is in relative motion and that in this case it tends to cool because of movement.

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